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A NUMERICAL ANALYSIS OF THE BACK PLANE TRANSIENT DEFORMATION OF A POLYCARBONATE PLATE

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February/février 2000

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01/01/26

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ABSTRACT

This report presents experimental and numerical studies of the back plane transient deformation of a 304.8-mm square, 4.76-mm thick, clamped polycarbonate plate impacted by a specially designed polycarbonate fragment simulating projectile. This was done to simulate the backplane transient deformation of a composite helmet. The maximum transient deformation of the back plane of the plate is presented as a function of the striking velocity. Numerical predictions of the transient backplane deformation, crater shape and the time at which the maximum transient deformation occurs are in close agreement with the experimental results. Both the numerical and experimental results show two peaks in the backplane transient deformation. It was observed that the maximum transient deformation varies linearly as a function of impact velocity for velocities above 90 m/s. Below 90 m/s the maximum transient deformation deviates from the linear curve. The numerical prediction of this anomalous behaviour compares very well with experimental observations. Numerical results also show that the reflected shock significantly influences the maximum transient deformation, especially for impact velocities above 90 m/s.

RÉSUMÉ

Ce rapport présente une étude numérique et expérimentale de la déformation transitoire d'une plaque carrée de polycarbonate de 304,8 mm de côté et de 4,76 mm d'épaisseur fixée solidement et frappée par un projectile de polycarbonate spécialement conçu pour simuler les effets d'un casque composite. La déformation transitoire maximale du côté arrière de la plaque est fonction de la vitesse d'impact du projectile. Les prédictions des simulations numériques de la déformation transitoire de la plaque et de la forme du cône d'enfoncement ainsi que le moment où la déformation maximale survient concordent très bien avec les résultats expérimentaux. On observe que la déformation transitoire varie de façon linéaire en fonction de la vitesse d'impact pour les vitesses supérieures à 90 m/s. Pour les vitesses inférieures à 90 m/s, la déformation transitoire s'écarte du modèle linéaire. Les résultats numériques de ce comportement inattendu se comparent très bien aux mesures expérimentales obtenues. Les simulations démontrent aussi que le choc réfléchi influence de manière significative la déformation transitoire maximale, surtout pour les vitesses d'impact dépassant 90 m/s.

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EXECUTIVE SUMMARY

The Defence Research Establishment Valcartier has been conducting a series of tests to investigate the back plane transient deformation of a polycarbonate plate. The aim of these tests is to develop an economical test method to evaluate and validate a HYBRID III head form to be used to conduct ballistic experiments. Ballistic helmets are quite expensive and a large number of helmets would be required to characterise the HYBRID III head form.

In this study, numerical techniques were used to examine the deformation process of a square clamped 4.76-mm thick polycarbonate plate impacted by a specially designed polycarbonate impactor. The striking velocities range from 25 to 200 m/s. The maximum transient deformation of the backplane of the polycarbonate plate is presented as a function of the impact velocity. Experimental tests were conducted to verify the numerical results. It was found that the numerical predictions compare very well with the measurements obtained using high-speed cameras (Hycam) photography to examine the back face deformation, the crater shape and the time at which the maximum transient deformation occurs.

The numerical simulations also showed that the maximum transient deformation varies linearly for velocities above 90 m/s. Below 90 m/s the maximum transient deformation deviates from the linear curve. The prediction of this anomalous behaviour again compares quite well with experimental observations.

These initial results show good promise that polycarbonate material could be used to reproduce the transient deformation of polymeric composite helmets although more detailed comparisons, including the back plane transient deformation, energy, and velocity all as a function of time, need to be performed. This work will certainly improve DND's capabilities in designing transparent armour systems, particularly given the large amount of resources involved when terminal ballistic experiments are required.

1.0 INTRODUCTION

The capacity of a polymeric composite helmet to stop fragments is highly dependent on a low resin content which generally results in large transient deformation during ballistic impact. Although the penetration of the helmet by a 1.1-g fragment (V_{50} test) is conventionally considered as one of the major criteria to estimate the ballistic performance of potential helmet materials, the transient deformation of the back plane of such helmets is also important as it may cause severe injuries to a soldier. A study by Bolduc and Nandlall (Ref. 1) investigated the maximum transient deformation of the back plane of a polymeric composite helmet. In this study they examined both experimentally and numerically the use of a copper liner to measure the maximum transient deformation of the back plane.

One of the basic underlying problems with helmet designs from a ballistic standpoint is that, because the skull lies very close to the surface of the skin, the head is unable to withstand the blunt trauma caused by the impact of a projectile. Studies (Ref. 2) have shown that such blunt trauma energy causes only a large bruise in the abdomen, whereas on the scalp it can cause a concussion. Since the head is quite close to the helmet, the stand-off distance between the helmet's back plane, the contact force and the amount of energy transferred to the skull become important factors when considering helmet design. To investigate these factors, the Defence Research Establishment Valcartier (DREV) has initiated a program to calibrate a HYBRID III headform to be used to conduct ballistic experiments. However, polymeric composite helmets are quite expensive and a large number of helmets are required to fully characterise the HYBRID III headform.

To overcome this problem, DREV has been conducting a series of tests to investigate the backplane deformation of polycarbonate plates with the aim of replacing the composite helmet with a more economical material for characterising the HYBRID III headform. The work presented in this report examines the deformation process of a

304.8-mm square, clamped, 4.76-mm thick polycarbonate plate impacted by a specially designed polycarbonate projectile.

This work was performed at DREV between October 1998 and May 1999 under Work Unit 2fh13, Ballistic Protection and Survivability, Numerical Modelling of Ballistic Events.

2.0 EXPERIMENTAL INVESTIGATION

2.1 Experimental Set-up

Figures 1 and 2 show, respectively, two views of the test set-up that was used to conduct the experiments.

FIGURE 1 - Picture of experimental test set-up

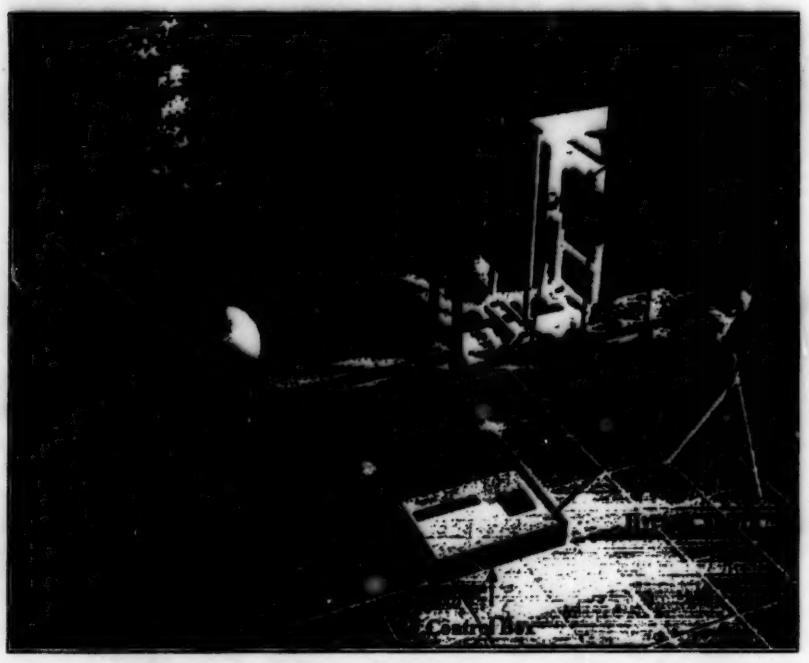

FIGURE 2 - Close-up detailed view of experimental set-up

A 825 kPa gas gun was used to accelerate the fragment simulating projectile. A laser beam, placed along the axis of the gun barrel, was used to align the gun with the target. Two light screens were used to measure the velocity of the projectile and were placed close enough to each other to minimise the projectile flight path between the gun and the target plate without affecting the accuracy of the measured velocity. This was done to ensure a perpendicular impact of the projectile onto the target plate. The HP 53131A 225 MHz timing unit system was used to measure the projectile travel time. Figure 3 shows a schematic view of the relative distances between the gas gun, the light screens and the target plate.

As shown in Figs. 1 and 2, the target plate is rigidly mounted within a square metallic fixture. Figure 4 shows the target fixture which consists of a 9.3-mm thick aluminium frame on the striking side of the target and a 9.3-mm thick steel frame on the backside. For velocities below 35 m/s, the steel frame thickness was reduced to 6.1 mm

to allow measurement of the backplane deformation of the polycarbonate plate on the high speed film.

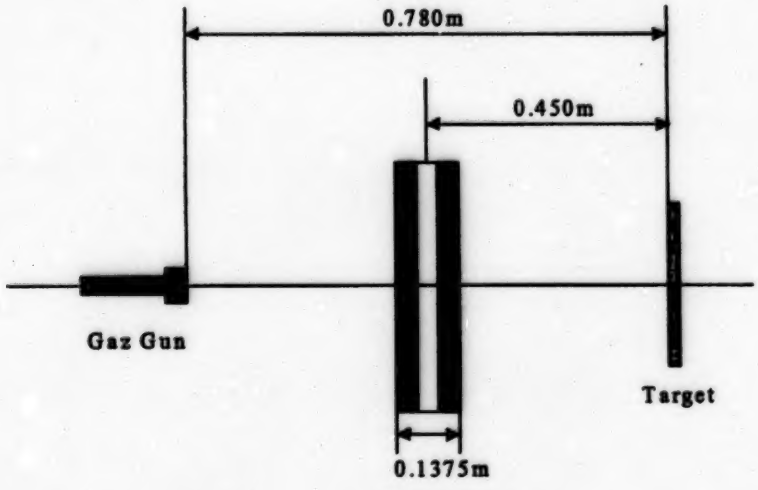

FIGURE 3 - Relative distance used in test set-up

FIGURE 4 - Close up view of target frame fixture

A Hycam camera, shown in Figs. 1 and 2, was used to measure the transient deformation of the back plane of the polycarbonate plate. The film speed was set at 11000 frames/s in order to precisely capture the maximum transient deformation. Two projector units ("Pal Light") were used to illuminate the target plate during test. A control unit was used to synchronise the firing of the gun with the camera and a white cardboard was used to increase the contrast of the picture. Since the polycarbonate plates used in the test series were transparent they were painted in black to improve the observation of the transient deformation.

2.2 Maximum Transient Deformation

Figure 5 shows a simplified diagram of the test set-up and the measurement of the maximum transient deformation.

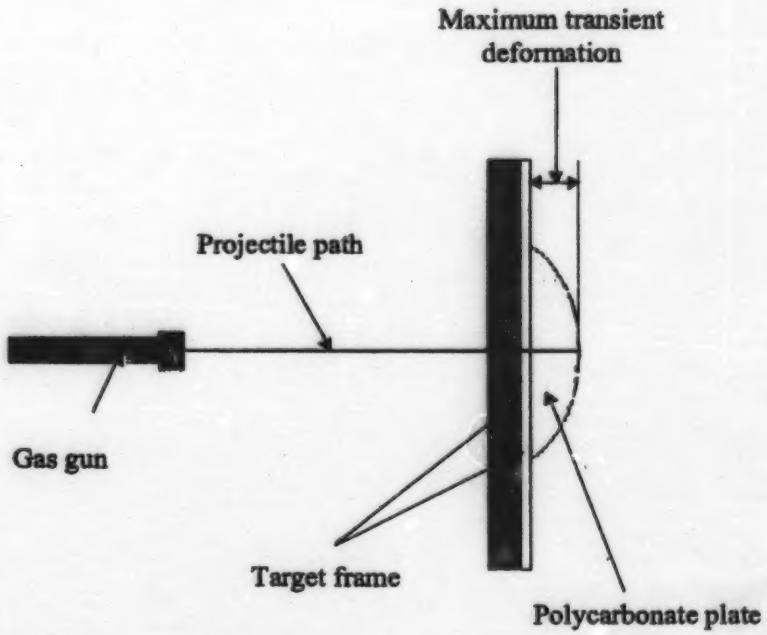

FIGURE 5 – Schematic diagram showing maximum transient deformation measurement

The maximum transient deformation is the maximum elastic deformation that occurs during the impact/penetration process of the target plate. This implies that the maximum transient deformation is only temporary and would disappear after the impact process is over. What remains is called the permanent or plastic deformation, and is generally of a smaller amplitude.

In this study the maximum transient deformation of the backplane of the polycarbonate plate is of primary interest mainly because, as in the helmet, it is the back surface that would impact and transfer the energy to the head.

2.3 Projectile and Target Description

Both the projectile and target are made from polycarbonate material commercially known as LEXAN. Figure 6 shows the main features of the specially shaped fragment simulating projectile.

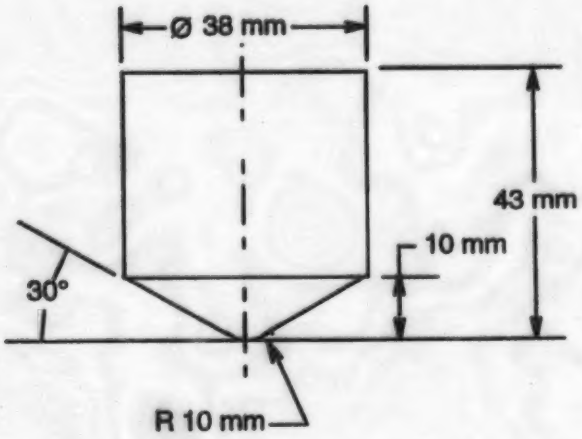

FIGURE 6 - Schematic drawing of the polycarbonate fragment simulating projectile

The basic projectile with a wide angle tip has a main 38.0-mm diameter cylindrical body and a hemispherical 10-mm radius tip. The wide angle at the tip of the projectile is 60° with respect to the axis of the cylindrical portion of the projectile.

The overall length of the projectile was adjusted to 43 mm in order to obtain the desired 50-g mass. The target is a 4.75-mm thick, 304.8-mm square polycarbonate plate clamped at the edges.

3.0 NUMERICAL SIMULATIONS

LS-DYNA3D (Ref. 3) is a 3-D hydrodynamic finite element computer code. It was used to examine the deformation process of the square 304.8-mm clamped, 4.76-mm thick polycarbonate plate impacted by the specially designed polycarbonate projectile.

The LS-DYNA3D hydrocode is an explicit three dimensional Lagrangian finite element code used for analysing the large deformation and high strain rate response of inelastic structures. LS-DYNA3D relies on a stand alone mesh generator to create the input files. In this study LS-INGRID (Ref. 4) was used as the mesh generator. Post processing of the results is also conducted by a stand alone processor. LS-TAURUS (Ref. 5) was used to perform the post-processing. LSDYNA3D normally requires two equations to conduct the numerical simulations. The first equation is a material constitutive model that describes the distortion of the material under stress while the other is an equation of state that describes the specific response of the material to volume change with pressure. The constitutive equation is a functional relationship relating the flow stress of a material to such parameters as strain, strain rate and temperature. The equation of state is a thermodynamic relation that compares/calculates the pressure, volume and a thermal parameter (internal energy or temperature). A more detailed description of LSDYNA3D is given in Ref. 3.

3.1 Numerical Mesh

To model the impact, penetration and deformation process that occurs when the projectile strikes the polycarbonate plate, and the subsequent deformation of the plate and projectile, it is necessary to divide the plate and the projectile into a finite number of regions called elements. The network of elements obtained is called a mesh. The

computations are then performed by solving the constitutive equations that describe the relationship between the forces and the displacements in the materials.

For clarity, Fig. 7 shows a half domain of the initial global finite element mesh that was used for the simulations. Due to the symmetric nature of the problem in two planes, only one quarter of the domain was considered. This quarter domain mesh was considered as the initial state just as the projectile impacts the target. Eight-nodes brick elements were used throughout the mesh. The 3-D quarter domain consists of a total 6509 elements of which 1325 are in the projectile and 5184 are in the target.

As shown in Fig. 7, a relatively coarse mesh at the outer regions of the geometry of the target plate, far from the impact zone, is used in order to minimise the computational time which could otherwise be extremely large. Numerical simulations have shown that the outer regions do not deform plastically and the coarse mesh can be used to minimise computational time (Ref. 4). On the other hand, the regions

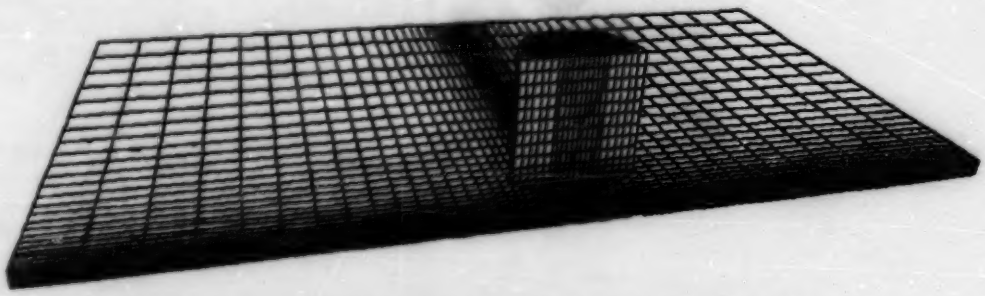

FIGURE 7 – Typical finite element mesh used for all simulations

immediately adjacent to the impact zone experienced large deformations and were therefore meshed more finely. This is also necessary to accurately model the contact between the projectile and target elements during the penetration process. For this study, a simple mesh sensitivity analysis was conducted. The mesh size was adjusted until the penetration or maximum transient backface deformation of the target plate stopped changing. The result was an optimum mesh size that was subsequently used for all the simulations performed in this study.

3.2 Material Models

For all the simulations presented, a kinematic/isotropic elastic-plastic hydrodynamic material model was used for both the projectile and target. The model assumes a bi-linear stress-strain behaviour while the strain rate is accounted for very simplistically through a scaling factor applied to the yield stress. Pageau et al. (Ref. 5) conducted an extensive experimental and numerical analysis of cylindrical polycarbonate projectiles striking steel plates. It was shown that the elastic-plastic constitutive model used for the polycarbonate material was capable of reproducing the experimental results quite accurately. Another study by Nandlall and Chrysler (Ref. 6) investigates the penetration of polycarbonate plates struck by five different types of fragment simulating projectiles. The numerical results obtained using the elastic/plastic model again compared quite well with the experimental values. The parameters used for both the projectile and target are given in Table I.

TABLE I

Material properties used for projectile and target

Material parameter	Polycarbonate projectile and target
Density, ρ (g/cm^3)	1.19
Elastic Modulus, E (Mbars)	0.02170
Poisson's ratio, ν	0.4
Yield strength, σ_y (Mbars)	$1.345*10^{-3}$
Tangent modulus, E_t (Mbars)	$0.68563*10^{-3}$

4.0 DISCUSSION OF COMPUTATIONAL AND EXPERIMENTAL RESULTS

Figure 8 shows a typical example of a simulation that was performed in an effort to examine the maximum backplane deformation and crater shape of the polycarbonate plate. In this case the striking velocity is 118 m/s. Simulations of the problem were performed at different impact velocities ranging from 20 to 180 m/s.

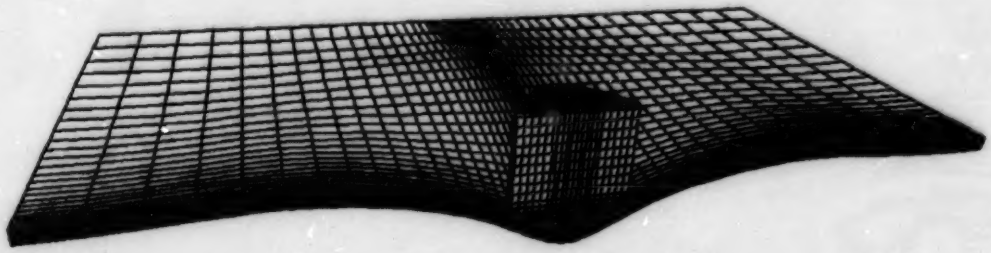

FIGURE 8 - Typical simulation performed to investigate the backplane deformation of a polycarbonate plate struck by a polycarbonate projectile

Figure 9 shows the transient deformation of the centre point of the backplane of the target as a function of time for six impact velocities ranging from 20 to 160 m/s. The curves shown are all obtained from numerical simulations. Examination of the curves shows that for all velocities there are two peaks in the transient deformation of the target's back plane. It also shows that the maximum transient deformation is always the second peak which occurs between 1300 μs and 2300 μs after impact, depending on the impact velocity. The first peak occurs between 650 μs and 950 μs after impact.

Close observation of the curves shown in Fig. 9 reveals that the difference between the amplitudes of the two peaks is quite small. However, it can be seen that the time lapse between the occurrence of the second peak relative to the occurrence of the first peak increases as the impact velocity is decreased.

Experiments were conducted for striking velocities ranging from 17 to 160 m/s and two peaks were also observed in the target's back plane transient deformation.

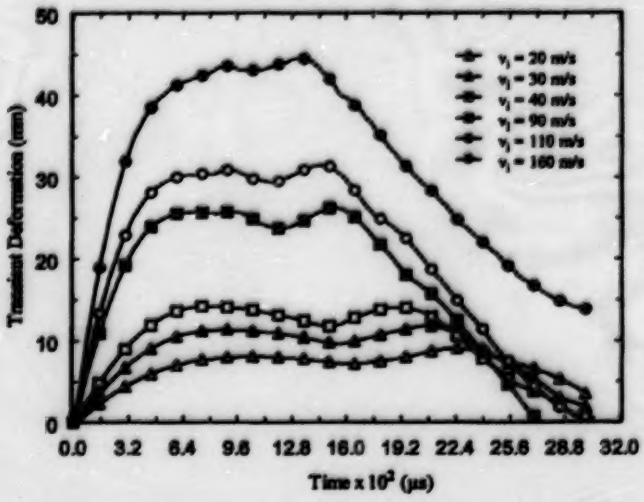

FIGURE 9 –Target's back plane transient deformation as a function of time for six different impact velocities ranging from 20 to 160 m/s

Table II shows the two peaks that were obtained for striking velocities ranging from 17 to 160 m/s. From Table II it can be seen that for striking velocities above 90 m/s the difference between the two peaks ranges between 4 to 10 mm. Below 90 m/s the difference is less noticeable, especially at lower velocities where the difference is about 3 mm.

Figure 10 shows the two transient deformation peaks for both the experiments and the numerical simulations as a function of the impact velocity. As can be observed, very good correlation was obtained between experimental and numerical values of the maximum transient deformation. However, for the first peak the correlation between the experimental value and the numerical value was not quite as good at higher impact velocities. However, in general, given the experimental scatter, the numerical results still compare quite well.

TABLE II
Experimental peaks observed in the target's back plane transient deformation

Velocity (m/s)	Transient Deformation Peak 1 (mm)	Transient Deformation Peak 2 (mm)	Velocity (m/s)	Transient Deformation Peak 1 (mm)	Transient Deformation Peak 2 (mm)
17	7.21	*N/A	52	11.90	22.10
18	7.98	8.86	53	16.80	*N/A
20	8.20	*N/A	53	14.48	9.32
21	8.76	*N/A	55	15.34	16.46
23	9.98	10.54	58	17.22	18.08
24	7.87	8.43	59	16.80	19.60
26	9.65	10.97	60	17.30	20.00
27	12.19	*N/A	60	15.67	19.20
28	10.64	*N/A	61	10.80	18.00
28	11.20	*N/A	74	21.80	24.90
31	11.63	12.75	76	19.30	23.60
31	11.86	13.31	76	18.00	21.80
33	11.53	13.84	96	25.90	32.30
35	11.18	11.18	99	25.10	28.70
35	11.07	15.52	100	21.80	25.90
36	10.64	12.62	117	26.70	35.60
37	15.00	*N/A	118	25.90	34.00
40	13.50	15.20	120	27.90	35.30
41	13.70	*N/A	134	29.20	34.00
41	12.40	12.93	136	28.70	38.80
43	13.06	14.91	137	31.20	41.70
46	14.71	14.71	139	30.70	39.10
46	12.62	13.59	161	37.80	46.00
47	14.15	14.25	162	36.60	46.00
48	14.71	15.04	166	39.40	49.30
49	13.16	14.25	169	41.40	51.60
50	13.39	15.47			

*N/A Unable to obtain second peak from high speed film

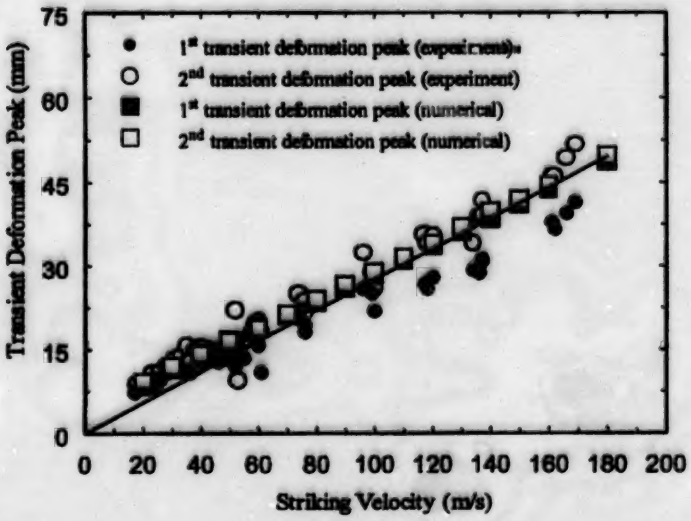

FIGURE 10 - Comparison of numerical and experimental transient deformation of the backface of the target plate

Careful observation of the results shown in Fig. 10 further reveals that, as the striking velocity drops below 90 m/s, there is a notable change in the structural response of the projectile/target system. This can be observed by noticing that above 90 m/s the maximum transient deformation varies linearly as a function of impact velocity, whereas below 90 m/s, the maximum transient deformation starts to deviate from this linearity. These results substantiate very much those shown in Fig. 9. This deviation from the linear trend results from a change in the structural response of the projectile/target system. At lower velocities the two peaks have about the same amplitude even though the occurrence of the two peaks are further apart than at higher impact velocities. This implies that as the impact velocity gets lower and lower the two peaks will disappear and only one peak will be observed as would be expected since it is anticipated that the curve will eventually return to the origin as the impact velocity approaches zero.

Figure 11 shows a comparison between a typical experimental transient deformation sequence and a numerical one. In this case the impact velocity is 118 m/s. For clarity, the numerical sequence shown is a section through one plane of symmetry. The experimental sequence shows the transient deformation of the entire target plate.

At 0 μs the projectile in both the numerical and experimental sequences is not as yet in contact with the target plate. At 875 μs the first peak of transient deformation of the backface of the target plate appears. At 1000 μs, close observation of the numerical simulation showed that a shock wave is reflected at the boundary and is returning towards the centre of the plate. Careful observation of the experimental and numerical results showed that maximum transient deformation of the backface occurs at 1500 μs when the projectile has already started to rebound and is not in contact with the target. This seems to suggest that at the time the maximum transient deformation occurs, the plate is not absorbing any more energy from the projectile, and that the maximum transient deformation is highly dependent on the reflected shock. At 2900 μs a wave motion of the plate recaptures the projectile and accelerates it away from the target.

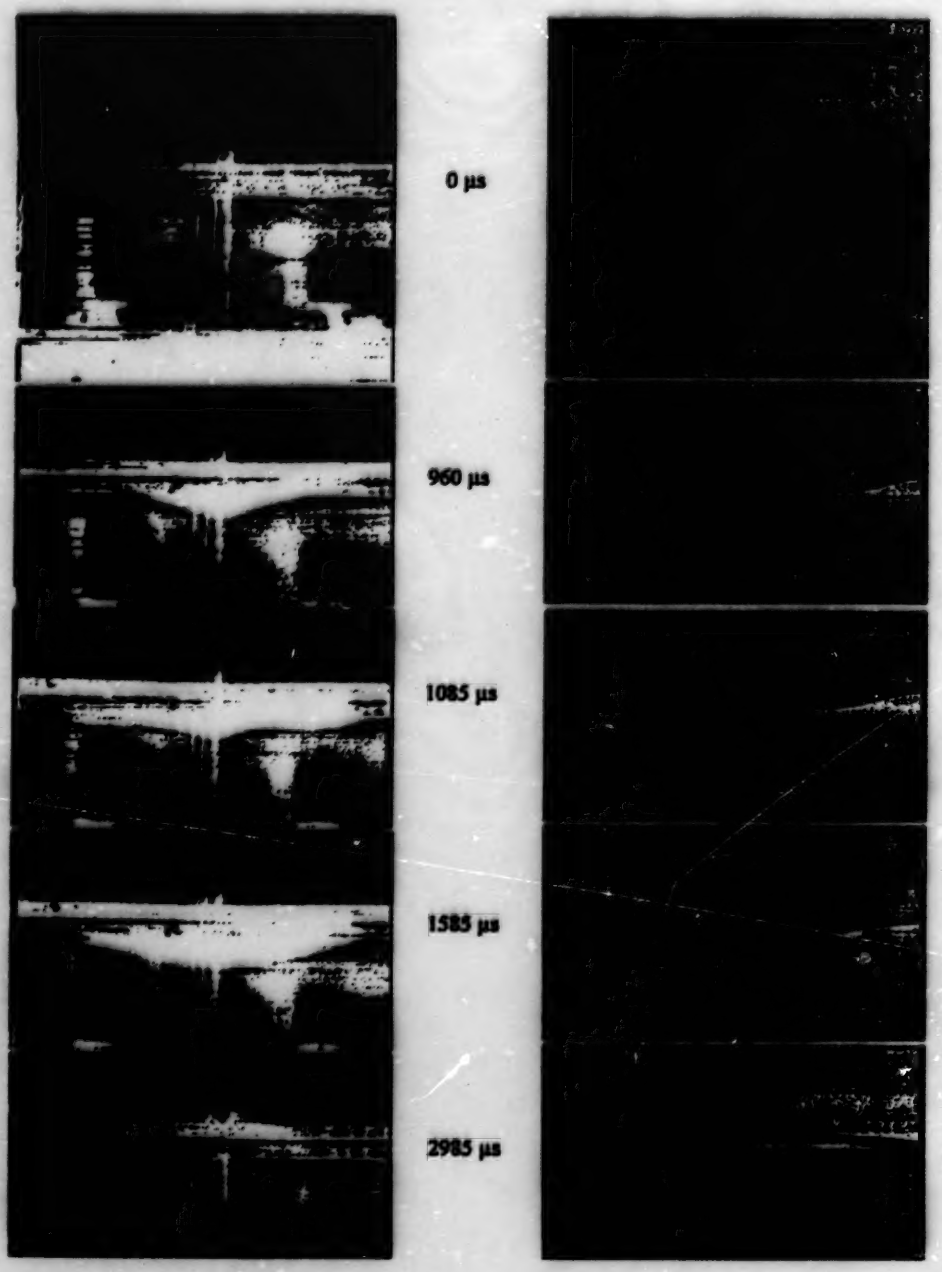

FIGURE 11 - Experimental and numerical comparison of target's backplane transient deformation. Projectile impact velocity is 118 m/s.

5.0 CONCLUSIONS

This study presents an experimental and numerical analysis that investigates the back plane transient deformation of a polycarbonate plate impacted by a 50-g specially shaped polycarbonate projectile at velocities ranging from 20 to 180 m/s. The experimental and numerical results compared quite well. Both the experimental and numerical results show that there are two peaks in the transient deformation of the back plane. It was seen that the second peak is always the maximum transient deformation and occurs when the projectile is not in contact with the target plate. The numerical simulations have shown that the reflected wave arriving at the centre of the plate causes the back plane of the plate to deform further and therefore forcing the transient deformation to arrive at its maximum even though the projectile and the plate are not in contact anymore. This implies that the reflected shock can significantly influence the maximum transient deformation.

The study also shows that for this particular projectile/target system the maximum transient deformation of the back plane varies linearly as a function of impact velocity for striking velocities above 90 m/s. Below 90 m/s the maximum transient deformation deviates from this linearity and occurs about the same time the structural response of the plate changes.

Finally, these initial results qualitatively show good promise that polycarbonate material could be used to reproduce the transient deformation of polymeric composite helmets. However, a more detailed comparison including the back plane transient deformation, energy, and velocity all as a function of time, needs to be performed.

6.0 ACKNOWLEDGEMENTS

The authors wish to thank Mr. Jacques Blais for the co-ordination and the ballistic testing performed. Thanks are also addressed to Mr. Guy Bilodeau and Mr. Jean Michaud for the operation of the high-speed camera. Special thanks are addressed to Dr. Grant McIntosh and Mr. Eric Fournier for their comments and review of this document.

7.0 REFERENCES

1. Bolduc, M. and Nandlall, D., "Evaluation of Transient Deformation of Military Helmets", DREV M-3170/94, September 1994, UNCLASSIFIED

2. Long, D., "Modern Ballistic Armour", Paladin Press, Boulder, Colorado, 1986.

3. Hallquist, J., "LSDYNA3D - An Explicit Three Dimensional Hydrodynamic Finite Element", LSTC Report 1004, Livermore Software Technology Corporation, 1990.

4. Nandlall, D. and Wong, G., "A Numerical Analysis of the Effect of Mesh Sensitivity on Ballistic Limit Prediction", DREV TM-9831, December 1998, UNCLASSIFIED

5. Pageau, G., Nandlall, D., Bolduc, M. and Bourget, D., "Fragmentation Resistance of Polycarbonate and Acrylic: A Numerical and Experimental Assessment", Proceedings PASS96 Symposium, Sept., 96, Colchester, UK.

6. Nandlall, D. and Chrysler, J., "A Numerical Analysis of the Ballistic Performance of a 6.35-mm Transparent Polycarbonate Plate", DREV TM-9834, December 1998, UNCLASSIFIED

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10a. ORIGINATOR'S DOCUMENT NUMBER	10b. OTHER DOCUMENT NOS
TR 1999 160	N/A

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

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This report presents experimental and numerical studies of the back plane transient deformation of a 304.8-mm square, 4.76-mm thick, clamped polycarbonate plate impacted by a specially designed polycarbonate fragment simulating projectile. This was done to simulate the backplane transient deformation of a composite helmet. The maximum transient deformation of the back plane of the plate is presented as a function of the striking velocity. Numerical predictions of the transient backplane deformation, crater shape and the time at which the maximum transient deformation occurs are in close agreement with the experimental results. Both the numerical and experimental results show two peaks in the backplane transient deformation. It was observed that the maximum transient deformation varies linearly as a function of impact velocity for velocities above 60 m/s. Below 60 m/s the maximum transient deformation deviates from the linear curve. The numerical prediction of this anomalous behaviour compares very well with experimental observations. Numerical results also show that the reflected shock significantly influences the maximum transient deformation, especially for impact velocities above 60 m/s.

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